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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of: Andrew Louis MARTIN	)	
	)	
	)	Group Art Unit: 3662
Application Ser. No. 10/784,686	)	Confirmation No.: 1929
	)	
Filed: 02/23/2004	)	
	)	Examiner: Ian J. LOBO
MEASUREMENT OF AIR CHARACTERISTICS IN THE LOWER ATMOSPHERE	)	

TRANSMITTAL

Transmitted herewith is/are: Transmittal (1 pg); Transmittal of Certified Copy (1 pg); Certified copy of Priority Document: Australian Application No. PR 7203 (37 pgs); Certified copy of Priority Document: Australian Application No. PR 7832 (8 pgs); and return postcard. This/These document(s) is/are being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on November 10, 2004.

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(Docket No.34746)

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Commissioner for Patents
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TRANSMITTAL OF CERTIFIED COPY

Attached please find the certified copies of the foreign applications from which priority is claimed for this case:

Country: AUS
Application No.: PR 7203
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Country: AUS
Application No.: PR 7832
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WITNESS my hand this
Eighteenth day of February 2004

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ORIGINAL

AUSTRALIA

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PROVISIONAL PATENT SPECIFICATION

Patent Application No:
Application Date:

APPLICANT: Tele-IP Limited [ACN 010 568 804]

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INVENTION TITLE: Detection of Wind-shear and Turbulence in the Lower Atmosphere

The invention is described in the following statement:–

TITLE: Detection of Wind-shear and Turbulence in the Lower Atmosphere

TECHNICAL FIELD

This invention relates to the use of acoustic pulses for atmospheric sounding and is particularly, though not exclusively, concerned with acoustic techniques for measuring air velocity variation – comprising horizontal wind speed variation, wind-shear and/or turbulence – in the lower atmosphere. The invention may, however, be applied to measuring local density variation in the atmosphere, such as may be caused by temperature gradients, thermal inversions and variations in moisture content.

The techniques of the invention are particularly suited to the measurement of wind profiling in the vicinity of airports to enhance air safety and/or permit higher density air traffic at airports.

BACKGROUND TO THE INVENTION

Accurate wind profiling near airports is most desirable to allow pilots to be informed of what to expect in the way of wind-shear (both horizontally and vertically) and to allow flight controllers to regulate the spacing between airplanes for landing and takeoff. At present, ground-based radar and other electromagnetic sounding techniques are of little use for the direct profiling of wind-shear below about 3000 m and, despite many trials, airborne radar is of little value in detecting clear-air turbulence [CAT] ahead of airplanes at cruising altitudes, let alone during landing and takeoff. At present, wind conditions below 2000 m in the immediate vicinity of airports are gauged by the release and radar or optical tracking of balloons. As this is expensive in terms of manpower and equipment, balloons are released at the most every few hours and usually once or twice a day. At ground level, of course, there is no problem in obtaining instantaneous accurate measurements of horizontal wind velocity and direction using anemometers.

Since wind-shear, or wind gusts (including ‘bullets’, gusts with predominantly vertical components), are transient phenomena, balloon tracking is of little value in warning a particular pilot what to expect during a particular landing at an airport. Consequently, the spacing between aircraft is set by ground controllers in a

conservative fashion and yet individual aircraft can still experience unusual and unexpected gusts when landing or taking off. It would thus be desirable to have an accurate and instantaneous method of profiling wind-shear in the vicinity of an airport.

OUTLINE OF THE INVENTION

The present invention is based upon the realization that acoustic chirps can be used to sound the low-level atmosphere in the vicinity of airports because the processing gain offered by comparing the transmitted and received chirps is very large and because wind-shear reflects or refracts sound waves in a detectable manner.

From one aspect, therefore, the present invention involves an acoustic sounding system wherein the component tones in a transmitted chirp are mixed, differenced, correlated or otherwise compared with the component tones in an echo chirp resulting from the reflection, refraction and/or scattering of the transmitted chirp. In this way, chirp transit times (and therefore the location of reflecting or refracting discontinuities in range) can be indicated as a frequency difference between the transmitted and the received chirps at any given instant. Furthermore, phase jitter or variation in an echo tone can be detected and displayed to indicate variation in velocity of the reflecting or refracting discontinuity with respect to the transmitter and/or receiver.

The transmitted acoustic chirp can be generated by feeding a loudspeaker with an electrical input signal from the sound card of a computer (for example), while the echo chirp can be detected using a microphone that generates an electrical echo signal. Though the effectiveness of both loudspeaker and microphone can be enhanced by using suitable reflector dishes, the acoustic power required in the pulse is tiny in comparison to that required for a high-power single-tone pulse of the art.

It will be appreciated, however, that many echo chirps will be generated by a single transmitted chirp because there will normally be many atmospheric

discontinuities within range. While the comparison can be done with analog systems using known mixer circuits, they may not be able to provide the discrimination required in demanding situations. It is therefore preferable to compare the input and echo signals in the Fourier domain using DSP (digital signal processing) techniques, the Fourier-transformed digital signals being subjected to complex multiplication to yield complex sums and differences from which the difference signal is normally selected. The result can be subjected to inverse Fourier transformation to generate amplitude and/or phase time series. The amplitude coordinate is the difference component (indicative of the discreteness of the discontinuity) and the time coordinate is indicative of the distance of the respective discontinuity from the transmitter and receiver.

In general, the chirp should have a tonal range (ie, acoustical bandwidth) suited to the object being sounded. We have found that low-level wind-shear is best sounded at the lower end of the audible range; for example, 500 – 5000 Hz, more preferably between 800 Hz and 3 kHz and most preferably between 1 and 2.5 kHz.

The tones in a chirp can be distributed in many ways. Most commonly, the frequency of the tones will increase or decrease linearly from the start to the end of the chirp. In this case, it is desirable to attempt to achieve a uniform rate of phase-shift from the start to the end of the chirp. Such linear chirps are more easily processed, especially using analog techniques. However, many other tonal sequences can be employed. For example, the frequencies can vary in a cosine manner, in steps or even in a random or pseudo-random manner. It is practically essential to process more complex chirps of this type using DSP and Fourier techniques.

Generally speaking, the longer the duration of a chirp the greater the potential processing gain of the system when using DSP and Fourier techniques. However, the processing power required to handle Fourier transformations and Fourier domain manipulations is also positively related to chirp duration. We have found that current readily available FFT algorithms, chips and DSP techniques known in

the art cannot handle chirps much longer than about 30 s duration in a practical manner. New generation FFT chips and techniques are likely to allow chirps of more than a minute to be processed.

Another consideration affecting the duration of the chirp is whether the echo signals are to be processed in real-time or off-line. The simplest approach is to process the echo signals in real-time and to make the transmitted signal (and chirp) of sufficient duration to ensure that echo signals start arriving before the input signal has finished. In this way, the frequency difference between the tones being transmitted and received (from reflection) at any instant is indicative of the distance of the boundary causing the reflection (for a linear chirp), and, the duration of the chirp will determine the range within which boundaries (or other targets) can be detected.

Comparison of the input and echo signals off-line – ie, not in real time – offers the advantage that the range of distances from which echoes are generated can be selected. Either or both the input and the echo signals can be recorded (before or after digitization and transformation) and then jointly played back with the desired time-offset to effect their comparison. For example, if signal processing considerations limit the chirp length to 15 s so that the maximum height at which boundaries can be reliably detected in real time is, say, around 5000', the input signal can be delayed by, say, 15 s after the transmission of the acoustic chirp, so that boundaries in the range of 5000 to 10000' can be detected using real-time echo signals by comparing the delayed signal with the echo signals arriving between 15 and 30 s after the start of the acoustic chirp.

While it will be normally desirable for the transmitted acoustic energy to be uniform over the chirp duration, or the same for each tonal increment of the chirp, the energy may be varied with respect to tone in order to compensate for anticipated frequency-selective attenuation in the environment being probed.

As indicated above, a convenient method of generating the chirp is to feed appropriate software (eg, MIDI commands) to a PC sound card so that the desired

tone sequence can be generated upon command. If a linear chirp is to be used, this technique allows the tone increments to be sufficiently small to create the effect of a continuous phase-shift – or smooth glissando – from beginning to end of the chirp. This input signal can be stored in a sound (wave) file in the PC and used generate repeated chirps at any desired time interval and, as already indicated, this input signal can be transmitted to a mixer for comparison with the echo signal at any desired time. Of course, acoustic chirps should not be transmitted so frequently that echoes from multiple chirps are received at the same time. If desired, a Fourier transformed input signal may be stored in the PC so that it can be fed to the comparator at the appropriate time for mixing with the transformed echo signal. This technique can reduce the real- time processing burden.

It will be appreciated that there will necessarily be direct transmission of the signal pulse from transmitter to receiver via the shortest route, as well as some indirect reflections from terrestrial objects. These 'direct' pulses may overlap the desired echoes in time at the receiver and degrade echo detection and processing. The direct pulse can be attenuated by acoustically isolating the transmitter and receiver, but this is often difficult or inconvenient. It can be subtracted from the echo chirp using known DSP techniques but, if the overlap of the direct and echo chirps is not great for the echoes of most interest, processing in the Fourier or frequency domain can effectively remove or discount most direct chirps. If the direct signals are not removed, the resulting amplitude-time display will show early high-amplitude returns that can be readily ignored in most cases.

We have found that the use of chirped acoustic sounders aligned with and cross-runway such that the chirped pulses are directed at a low elevation allows wind-shear and CAT in the vicinity of a runway to be identified. Mirrored transmitter and receiver sets are used in each direction so that pulses can be transmitted first in one direction and then in the other. The height of the wind-shear or CAT can be estimated by the time delay between transmission and reception of the reflected or refracted pulses, while the velocity of the associated body of air in the pulse-beam direction can be estimated by comparing the differential time shifting of the

'up' and 'down' pulses. The component time-delay measurements that allow the differential comparison can each be obtained using the techniques indicated above, yielding a highly accurate measurement of wind velocity or turbulence at any desired height within range. In general, chirp transit-time measurements conducted in this way will be more accurate than Doppler-based measurements.

However, we have found that it is often difficult to interpret the results obtained from systems in which the chirp is transmitted and received at relatively low angles of elevation. We are uncertain of the reason for this but suspect interference with Doppler shifts in the echo chirps. Surprisingly, we have found good results in detecting and quantifying both horizontal and vertical wind components at altitudes up to about 3000 meters in systems where the transmitted chirps are directed substantially vertically upwards, multiple receivers are arranged (preferably symmetrically) around the transmitter within about 20 m and where the echo chirps are differenced or combined to yield a composite result.

It was also surprising for us to find that the best results were obtained with receivers located at no more than about two meters from the transmitter. Indeed, receivers (microphones) can even be located in the same 2 or 3 meter dish as the transmitter with good results. The most convenient number and configuration of receivers/microphones is four, one pair being arranged on the North-South axis symmetrically about the transmitter and the other pair being arranged on the East-West axis symmetrically about the transmitter. The use of three microphones arranged symmetrically around a transmitter is also satisfactory but leads to unnecessary complications in signal processing to obtain directional indications of wind velocities at various heights. Of course, two microphones may be arranged symmetrically on either side of a transmitter to obtain measurements for wind-shear along the resulting (say, North-South) axis and a similar transmitter and pair of microphones can be used to obtain measurements along another axis (say, East-West).

As already indicated, the microphones can be closely spaced by being mounted off-center in the same dish as the transmitter, or they can be spaced further apart, each in its own dish or antenna. The invention also envisages the use of a single dish having a central transmitter and one offset microphone, the dish being rotated through a defined angle (conveniently 60 or 90 degrees) after each sounding to simulate a stationary dish with multiple (conveniently three or four) microphones. Where separate dishes at wider spacing from the transmitter are used for each receiver/microphone, it is desirable that each dish be tilted slightly toward the axis of the vertical axis of the transmitter. Angles of between about 1 and 10 degrees have been found suitable, it not being important to set the angle to a particular height at which the axis of a receiver intersects that of the transmitter. Indeed, highly satisfactory results have been obtained where the receivers have been located 1 meter apart in the same dish as the transmitter so as to be angled at about 5 degrees to the vertical. Obviously, with such an arrangement, the intersection of the receiver and transmitter axes bears no relation to the height at which wind-shear is being observed, which is determined by the delay between transmission and reception.

In the convenient arrangement where four receivers are arranged in quadrature, the processed signals received from the North and South receivers are differenced to provide an indication of wind velocity and phase variation with height (transit time) and the processed signals received from the East and West receivers are similarly differenced.

The invention can be embodied in apparatus, systems or methods for acoustic sounding in air.

DESCRIPTION OF EXAMPLES

Having portrayed the nature of the present invention, particular examples will now be described with reference to the accompanying drawings. However, those skilled in the art will appreciate that many variations and modifications can be made to the chosen examples without departing from the scope of the invention as outlined above. In the accompanying drawings:

Figure 1 is a series of diagrammatic plan views showing selected arrangements of transmitters and receivers, the transmitters (loudspeakers) being shown as small shaded circles and the receivers (microphones) being shown as small unshaded circles.

Figure 2 is a series of diagrammatic elevation views showing co-located and separately located transmitter and receiver arrangements.

Figure 3 is a block diagram showing the principal components of a differential acoustic sounder having one transmitter and four symmetrically spaced receivers, two on the North-South axis and two on the East-West axis, only the two on the East-West axis being shown.

Figure 4 is a simple block diagram showing the transmitter and the West receiver of Figure 3 and the paths of one chirp being reflected from the upper and lower boundaries of a wind-shear channel or layer.

Figure 5 is a set of graphs showing a simple process whereby a transmitted chirp (a) can be combined with echo chirps (b) and (d) to generate useful outputs (c) and (e).

Figure 6 is a more detailed block diagram of a sounding system employing Fourier domain comparison or mixing.

Figure 7 is a flow-chart depicting a procedure for Fourier-domain processing of the transmitted and echo chirps in the system of Figure 6.

Figure 8 is a graph, derived from radiosonde measurements, showing variation of air temperature (**Te**) and moisture (**M**) with altitude at Melbourne, Australia, on 28 February 2001.

Figure 9 is a graph charting output signal amplitude with respect to altitude derived from the system of Figure 6 at Mulgrave (a Melbourne suburb) on 28 February 2001.

Figure 10 is a black and white reproduction of a series of color graphs of reflections obtained at various altitudes for many repeated soundings taken over 40 minutes on 28 February 2001 at Mulgrave; graph **A** showing color-coded amplitude data; graph **Ar** showing the red (high amplitude) component of graph **A**; graph **P** showing color-coded phase data; graph **Pr** showing the red (high phase) component of graph P; graph **R** being a reference color spectrum.

Figure 11 is a diagrammatic side elevation of the apparatus of a further example of the invention for measuring wind speed and direction (both vertical and horizontal) above a location.

Figure 12 is a black and white copy of a color printout obtained from the system of Figure 11 showing variation of turbulence (vertical wind velocity) and wind direction with height.

Figure 13 is another graph showing variation of wind direction and height obtained from the system of Figure 11.

Figure 14 is a graph showing total phase difference between the East and West signal paths of the system of Figure 11, the vertical scale being in arbitary units and the horizontal scale being sample number, which can be related to height given a sampling rate of 96.6 k/s.

Figure 1 is a series of simple plan-view diagrams, (a) to (g) showing some possible configurations of sets of acoustic transmitters and receivers that are envisaged by this invention, though there will be many others. Diagram (a) shows a convenient and economical configuration in which four microphones (receivers) Rx are spaced around a common parabolic reflector dish D and a single loudspeaker Tx is located in the central focus of the dish. In this way, the amplitude lobe of the transmitted pulse is vertical but the amplitude lobe each received echo is angled to the vertical (and towards the axis of the dish) by up to 10 degrees, depending upon the shape of the dish and the distance between each receiver Rx and the common transmitter.

Diagram (b) of Figure 1 shows three receivers evenly spaced in a common dish that also has a centrally located transmitter. Diagram (c) shows a dish with a central transmitter and only one offset receiver, the dish being mounted so that it can be rotated to successively put the single receiver in different positions [eg, those illustrated in (a) or (c)]. Diagram (d) shows four receivers mounted in a common receiving dish Rxd that is separate and spaced from the associated transmitter mounted in its own transmission dish Txd. Of course, receiving dish Rxd may have three rather than four receivers located therein. Diagram (e) illustrates a configuration in which each of four receivers RxN, RxS, RxE and RxW has its own receiving dish Rxd and the single transmitter also has its separate dish Txt. Diagram (f) is similar to (e) except only three receivers and their dishes are employed. Finally diagram (g) shows a configuration in which a single receiver and its dish are mounted so as to be rotatable around a single transmitter and its dish, so as to be able to simulate configurations such as those of (e) and (g).

The diagrams (A), (C) and (E) of Figure 2 are elevational views of configurations (a), (c) and (e) respectively of Figure 1.

Figure 3 illustrates one simple way of processing the signals in the arrangement of Figures 1 (a) and 2 (A) or of Figure 1 (e), where a single transmitter is used with a pair of laterally spaced East-West receivers, shown as RxE and RxW. The transmitter Tx is shown as a horn without a dish in Figure 3 for convenience.

Transmitter Tx is driven by a driver circuit DTx to generate a series of time-spaced chirps and to direct them vertically upwards. Echoes from these chirps detected by receiver RxE, along with the outgoing signal from driver DTx (perhaps after being subject to predetermined delay) are fed to a mixer MxE circuit, the output Oe of which is indicative of turbulence and wind-shear detected in the easterly direction. Similarly, echoes from these chirps detected by receiver RxW, along with the outgoing signal from driver DTx (perhaps after being subject to predetermined delay) are fed to a mixer MxW circuit, the output Ow of which is indicative of turbulence and wind-shear detected in the westerly direction. Finally, outputs Oe and Ow are differenced or mixed in mixer circuit Mo to generate a composite output Co indicative of the net East-West wind speed and turbulence at various heights.

The functional principles of the acoustic sounding system of Figure 3 will now be explained with reference to the simple diagrams of Figures 4 and 5. It will be assumed that a pair of wind-shear boundaries 2a and 2b define an intermediate layer **D** of wind having a different velocity and/or direction to the layers above and below. The intermediate layer is sometimes called a duct because it causes disturbances to the transmission of radio waves. If the wind velocity and direction and/or air density within the duct **D** are significantly different from those in the layers above and below, the boundaries 2a and 2b of duct **D** are likely to be turbulent, as illustrated by the ripples in these boundaries in Figure 4. Such conditions can present hazards to aircraft during the approach to and takeoff from airports.

System 1 (Figure 4) includes (i) a transmitter 3 – a loudspeaker directed vertically upwards – (ii) a receiver 4 – a microphone and reflector dish also pointed vertically upwards – receiver 4 being located on the same site as transmitter 3 but a few metres away therefrom, (iii) an input signal generator 5 and (iii) an electronic mixer or comparator circuit 6. [Transmitter 3 may be transmitter Tx of Figure 3 and receiver 4 may be either the East receiver Rxe or the West receiver Rxw of Figure 3.] Input signal generator 5 generates electronic input signals

(chirps) that are conveyed to both transmitter 3 and mixer 6. These input signals result in acoustic chirps being transmitted from transmitter 3 and echo chirps being received by receiver 4. The path of chirps generated by transmitter 3 and reflected from the lower boundary 2a is shown by unbroken line 7a while the path of a pulse reflected from upper boundary 2b is shown by broken line 7b. Echoes received by receiver 4 are converted into electronic echo signals and fed to mixer 6. Mixer 6 is shown as having two outputs, indicated as 8 and 9. Output 8 indicates the magnitude of an echo, while output 9 indicates the phase shift in the echo, both outputs being a time series indicating successive echoes from successively greater altitudes. The phase shift signal indicates the vertical velocity of atmospheric discontinuities – or turbulence – at the altitude of the echo.

Figure 5 is a series of graphs illustrating, in a simplified way, the manner in which a chirp **T** from transmitter 3, a first echo chirp **Ra** reflected from boundary 2a and a second echo chirp **Rb** reflected from boundary 2b can be processed to yield an output signal indicative of the height of the boundary layers. Chirp **T** is assumed to be of 15 seconds duration and increases linearly in audio frequency from 1.4kHz to 2.4kHz. It is repeated at intervals of not less than 15 seconds between chirps. Received echo chirps **Ra** and **Rb** are shown as if they had not been attenuated during transmission and reflection through the atmosphere whereas, in practice, they will be substantially attenuated and contain significant noise. However, those skilled in the art will appreciate that the amplitudes of the transmitted and received pulses can be automatically adjusted or 'normalized' so as to be comparable.

A simple method of processing the chirps to derive distance information is to (i) sample each using a common clock, (ii) detect each audio tone received and (iii) subtract the detected tone(s) from the tone of the transmitted chirp during each sample period. This can be done for the entire duration of the transmitted chirp or for only that portion of the transmitted chirp corresponding to the altitude range of particular interest. Thus, subtracting the detected tone of received chirp **Ra** from the tone of transmitted chirp **T,** instant by instant, will yield a signal **T-Ra** of the type shown in graph (c), the dashed lines indicating the portion of chirp **Ra** that is normally ignored or discarded by mixer 6 because it occurs after the end of

transmitted chirp **T**. It will be seen from graph (c) that from 0 – 4 s only the tones of input chirp **T** are received (direct from signal generator 5) but, from 4 – 15 s the rising tones of chirp **Ra** are detected and are subtracted from the tones of chirp **T** to yield a constant difference tone **Fa** (shown hatched) that is indicative of the height of boundary 2a and appears as an output signal on line 8.

After 11 s, the tones of chirp **Rb** start to be detected. Being near the start of echo chirp **Ra**, these low frequency tones are easily discriminated from the high frequency tones near the end of chirp **T**. Thus the tones detected from **Rb** can be separately subtracted by mixer 6 from those of chirp **T** to yield a difference tone **Fb** that persists from 11 – 15 s, as shown by the hatched area of graph (e). **Fb** is, of course, indicative of the height of boundary 11b and appears as an output signal on line 8 some time after the appearance of **Fa** on line 8. The amplitude of signals **Fa** and **Fb** (not shown in Figure 5) are indicative of the reflectivity of boundaries 2a and 2b and their timing is indicative of the altitudes of the boundaries. The dashed portion of graph (e) indicates the form of the processed signal **T-Rb** if chirp **Rb** was the only one received and if the whole of chirps **T** and **Rb** were taken into account by mixer 6. In fact, it would be normal for mixer 6 to ignore (ie, equate to zero) all tones of chirp **T** received when no tone is detected by receiver 4, and, to ignore all tones detected by receiver 4 before and after the transmission of chirp **T**.

From graphs (a), (b) and (c) of Figure 5, it will be seen that there are 11 s during which the tones of **Ra** can be processed to yield signal **Fa** on output 8, but there are only 4 s during which the tones of **Rb** can be detected and processed to yield output **Fb.** If chirps are transmitted every 20 s, three sets measurements can be taken every minute and added to the integration of **Fb** to improve its accuracy. Should more accuracy be required in measuring the height of boundary 2b, a replica of input signal or chirp **T** can be generated, delayed by say 7 s, and then compared with received chirp **Rb** to provide an overlap of 11 s; the added 7 s delay being taken into account when calculating the height of boundary 2b.

An indication of the range of sounder 1 employing a 15 s chirp can be had by assuming for convenience that the speed of sound in air approximates 1000 ft/s and that the echoes of interest must be received between second 4 and second 11 of the transmitted chirp to allow effective analysis. Thus the altitude range that can be encompassed will be between 2000' and 5500'. It will also be appreciated by those skilled in the art that, if the input signal and the echo signal are sampled at a high rate (say 44.1 kHz) and each sample is it is fed through an A/D converter and digitized and the thus digitized input and echo signals are subjected to Fourier transformation, the mixing or comparison of these signals can be effected in the Fourier domain, resulting in very high processing gains and accurate measurements well below 2000'.

Referring now to Figures 6 and 7, an embodiment will now be described that compares the transmitted and received pulses using Fourier techniques. A PC (personal computer) can be used to implement chirp-generation software that produces a linear-sweep cosine analogue chirp signal of a 1kHz range, from 1.4kHz to 2.4kHz, such that the phase of the signal increases linearly over a period of 15s, which is the duration of the chirp in this example. This analogue signal is output from the sound card 24 of the PC to an audio power amplifier 26 that drives loudspeaker 14 and is sampled by sampler unit 28 at about 44.1kHz. Each sample is converted into a digital code indicative of the phase and amplitude of the signal of the sample. If desired, the output analogue chirp signal and/or the digital output of sampler 28 is/are recorded in recorder 30, but it will be appreciated by those skilled in the art that it will be convenient to implement such recordings by saving the analogue and/or digital signals to RAM or to disc as computer-readable files.

The returned analogue signal detected by microphone 20 is amplified in a preamplifier 32 and sampled and digitized (phase and amplitude, preferably) by sampler 34, preferably at the same rate (44.1kHz) and using the same A-D coding (eg, 16 bit) as employed for the output chirp was by sampler unit 28. Preferably, the sampling of the received signal by unit 34 is initiated at the start of the transmission of the chirp, or after a predetermined delay. The broken line 36

illustrates this synchronization, though it will be appreciated that the synchronization signal indicating the start of a transmitted chirp can be generated by the PC rather than by employing detector means (not shown) in sampler unit 28 to identify the start of a chirp. As with the transmitted signal, the received signal can be recorded by recorder 38 in analogue form from the output of preamplifier 32 or as the sampled and digitized signal output by sampler 34. Again, it may be convenient to implement the recording within the PC using RAM or disc storage media. In fact, most system functions can be PC implemented.

In this example, comparison or correlation of the transmitted and received chirps is effected in the Fourier domain by multiplying the Fourier transform of each pair of samples using a multiplier unit 40 of a type known in the art. In this example, transformation of each successive sample of the outgoing chirp is effected by a Fourier transformer 42 that employs a FFT algorithm and each successive sample of the received signal is transformed in a similar fashion using transformer 44. It will be appreciated that FFT devices 42 and 44 can be implemented in hardware or in software, both of which are available commercially. Hardware devices, usually being significantly faster than software devices, will usually be preferred if the transformation is to be conducted in real time (as indicated by arrows 46 and 48). However, an FFT algorithm can be implemented in software by the PC and may be preferred for cost reasons, but this may require that the transformations are effected off line. This is indicated by broken arrows 50 and 52 indicating that the recorded signals are fed from recorders 30 and 38 via samplers 28 and 40 to FFT devices 42 and 44, respectively.

As already indicated, complex multiplier 40 will generally yield both a positive and a negative results, only one of which is required. If desired, the selected output of multiplier 40 can be displayed in the Fourier domain relative to time or sample number on a suitable CRT or other display device to indicate detected boundaries. However, such Fourier charts are not readily interpreted by non-specialists and it will be generally preferably to perform and inverse Fourier transform on each complex product output from multiplier 40 using an inverse FFT device 54 to yield a voltage of proportionate amplitude in the time domain, which

can be fed (via line 55 as indicated in Figure 6) to a display device 56 (normally the screen of the PC) and shown thereon as a Y-axis histogram or vertical bar. The X-axis of display 56, representing time or sample number, can be derived directly from the computer (via line 58), from the output chirp signal on line 60 and an auto-correlator 62, or via a synchronizing signal on line 64 derived from line 36.

It will also be appreciated that a high amplitude direct chirp signal, indicated by broken-line arrow 66 in Figure 6, will be received by receiver 20 almost immediately upon transmission, since the distance between transmitter 16 and receiver 20 is only a few meters. This direct signal could be removed to enhance the overlapping lower amplitude signals received from boundaries such as 18 by auto-correlation and other techniques in device 62, in an analogue device 68 connected between the transmitter and receiver sections prior to samplers 28 and 34, or in a digital device 70 connected between the transmitter and receiver sections after samplers 28 and 34. However, as previously indicated, removal of the direct signal from the received signal is generally not necessary nor very advantageous because the comparison of the transmitted and received signals in the Fourier domain accomplishes that task to a remarkable degree. However, during the time between the start of reception of the direct and indirect signals, there will be a large resultant net signal due to the directly transmitted chirp. So long as the sampling and digitization processes are capable of handling the large amplitude signal, no deleterious interference between the signals should be found. A sampling rate of at least 30kHz and 32 bit digitization are desirable, but not essential for this purpose.

Figure 7 is a flow chart indicating the actions described above as a time sequence This chart will be self explanatory to those skilled in the art. Lines 80 and 82 indicate the real-time analysis option in which the results from the sampling steps 28' and 34' are input directly to the respective FFT transform steps 42' and 44'. Discontinuities 86 and 88 indicate the variable time lapse between sampling steps 28' and 34' and the performance of the FFT transforms in steps 42' and 44'. This time lapse is permitted by first recording the sampled transmitted and received signals in recording steps 30' and 38' and then, at some later time indicated at 86

and 88, retrieving the sound files in steps 90 and 92 and performing respective FFTs in steps 42' and 44'. Optionally, but by no means necessarily as indicated above, the direct signal transmitted on path 66 (Figure 6) could be removed from the received analogue signal in step 68' and/or from the sampled digital signal in step 70'. This may be done by auto correlation methods or simply by system calibration conducted when there are no boundary reflections, or when the reception of such reflections is delayed beyond the duration the direct signal on path 66. It has been found that removal of the direct signal in this manner seldom offers significant advantage because the processing gain of the system is so high.

The sampling rates and chirp duration indicated in the above example can provide processing gains of around 55dB, permitting a precision of measurement of about one metre in 500. It will be appreciated that this is greatly superior to that which can be achieved by the simple pulse timing methods of the prior art.

Figure 8 is a standard graph of radio-sonde data collected at Melbourne airport in the morning of 28 February 2001 and posted on the Internet by the University of Wyoming. It depicts the variation of temperature **Te** and moisture **M** with height. It will be seen that there is a major temperature discontinuity between about 1013 and 1200 m, a minor inversion at 1491 m and a major inversion at about 3000 m. Figure is an actual plot of the type indicated at 36 in Figure 6 charting reflection amplitudes against altitude taken on in the afternoon of 28 February at Mulgrave (a Melbourne suburb about 40 km from the Melbourne airport). It will be seen that, for the purpose of predicting the location of boundaries and their relative reflective strength, the graph Figure offers much greater detail than that of Figure 8. While the major discontinuity around 1200 m is still dominant, the simple inversion between 1400 and 3000 m in graph Te of Figure 8 is revealed as a much more complicated structure in the graph of Figure 9, showing a likely duct between 1950 and 2700 m. Though much of the fine detail shown in Figure will not be of relevance to the design of a microwave link, it will be of significant interests to meteorologists, those concerned with plume and pollution dispersal and to atmospheric researchers generally.

The graphs of Figure 10 illustrate the results of repeated soundings taken on 28 February 2001 using 15 s chirps taken over a 40-minute sampling period using the system of Figures 6 and 7. Graph **A** shows amplitude variation with height and graph **P** shows phase variation with height. The echo signals have been arbitrarily clipped to a transit times corresponding to an altitude of about 900m. These graphs are reproductions of color graphs that, unfortunately, loose much of their detail in black and white. In the color version, bar **R** is a reference spectrum in which blue is at the bottom and red at the top with yellow and green between. In graph **A,** most of the portion below 250 m (the boundary layer) is blue showing low echo amplitudes (i.e., few significant thermal discontinuities). Graph **Ar** shows the red and near-red components of graph **A** and reveals an area of high reflectivity (large thermal discontinuities) between about 550 and 800 m. In graph **P**, most of the region below the boundary layer is blue, showing a low phase shifts and, therefore, low vertical wind velocities. Graph **Pr** shows the red and near-red components of graph **P** indicating significant turbulence above the boundary layer. Again, such graphs will be of interest to many others besides those who wish to pin-point the causes of multipath fading in a microwave link.

The system of Figure 11 provides an example of the invention suitable for measuring both horizontal and vertical wind speed over a particular location, such as an airport. This system eliminates the need for widely separated transmitters and receivers and the associated interpretational difficulties mentioned above. The results obtained from such a system are shown in Figures 12-14 and will be discussed below.

The system 100 of Figure 11 comprises a large main dish 102 and a small secondary dish 104 mounted directly above the main dish. A transmitter/receiver module 106 is supported centrally above large dish 102 (by struts that are not shown) and, in turn, supports small dish 104 on the top thereof. Module 106 comprises a sound-adsorbent moulding 108, into the bottom of which a central loudspeaker/transmitter 110 and four peripheral microphones/receivers are fitted.

The microphones are arranged in quadrature, being aligned North, South, East and West. In the sectional diagram of Figure 11, the East microphone is shown at 112 and the West microphone is shown at 114. The axis of each microphone is angled to the vertical at between about 5 and 10 degrees. The transmitter 110 and receivers 112 and 114 are located near the focus of large dish 102. A fifth directional microphone/receiver 116 is located at the focus of small dish 104.

In the diagram of Figure 11, a single horizontal reflective atmospheric discontinuity, or TIL, 120 is shown. Since transmitter 110 is pointed vertically downward, it will generate a downwardly directed vertical beam of pulses that will be reflected vertically upward by large dish 102 and then reflected vertically back to receiver 116 on small dish 104. This central axis or vertical path is shown diagrammatically at 122, but it will be appreciated that the beam of interrogating pulses will be conical and will illuminate a significant area of the TIL 120 around central axis 122. Some of the sound reflected downward from TIL 120 to the East of axis 122 will travel along the axis 124 of East receiver 112 and be most strongly detected by that receiver (in comparison with the signals detected by the other receivers). Similarly, some of the sound reflected downward from TIL 120 to the West of axis 122 will travel along the axis 126 of West receiver and be most strongly received by West microphone 114. It will be appreciated that, because of the reflection of the received signals on paths 124 and 126, East microphone 112 is mounted to the West of transmitter 110 and West microphone is mounted opposite to the East of transmitter 110.

Again, it is to be noted that, while the sound which is reflected from TIL and detected by the East receiver 112 may be centered about path 124, receiver 112 will be sensitive to sound reflected from a large area of the TIL, one which is likely to overlap with the reflecting areas corresponding with each of the other receivers at any significant altitude. It will also be appreciated (as indicated previously) that there will be many atmospheric discontinuities with altitude, that these discontinuities may take the form of ducts or bands, and that there will be acoustic reflections from each. Nevertheless, it is convenient for the purpose of the following discussion to make the highly simplistic assumption that there is only

one reflective discontinuity (TIL 120), that the reflected sound from TIL 120 travels along paths 122, 124 and 126 to the receivers, that TIL 120 will be rippled (ie, its altitude will vary) with the turbulence of the associated layer and that TIL 120 will have a horizontal velocity indicative of wind-shear at the altitude of the layer.

Chirps reflected vertically downwards from TIL 120 on path 122 to receiver 116 on small dish 104 can be used in the manner described in the examples above to indicate variations in the vertical velocity (turbulence) of TIL 120 on axis 122, even where there is substantial wind-shear. If the ripples in TIL 120 have long wavelengths (in the order of kilometers) and low amplitudes (indicating low turbulence) then processing the signals received by each of the five receivers will yield similar results, all being indicative of the height of the TIL at the time of measurement. If the ripples in TIL 120 have a shorter wavelength and large amplitude, it is highly likely that the processed signals from each microphone will differ substantially because the height of the TIL at the intersection of axes 122 124 and 126 can be expected to differ significantly at any instant.

If it is assumed that there is substantial wind-shear, say that the TIL being blown from the East toward the West, then it can be imagined that the length of path 124 to the East receiver 112 will be shorter than path 126 to the West receiver 114 because of the horizontal motion of the layer 120. This difference in path length, which is indicative of E-W wind speed, can be computed by determining the phase difference between the signals received by receivers 112 and 114. Since signals are in fact being reflected from many layers at many heights, the phase common phase shift represented by altitude can be extracted or 'unwound' from the received signals to yield a vertical profile of wind velocity in the E-W direction. The same can, of course, be done in the N-S direction and the wind direction can be readily computed and depicted as a compass bearing.

Figure 12 is a composite series of graphs showing the readings obtained from the system of Figure 11 during one series of measurements. The variation of wind turbulence with altitude, and of wind direction on the E-W and N-S axes with altitude, are shown. In addition, the amplitude of the returned signals (to receiver

116) with altitude is depicted as a colour chart bar (but this cannot be clear in the black and white reproduction of Figure 12).

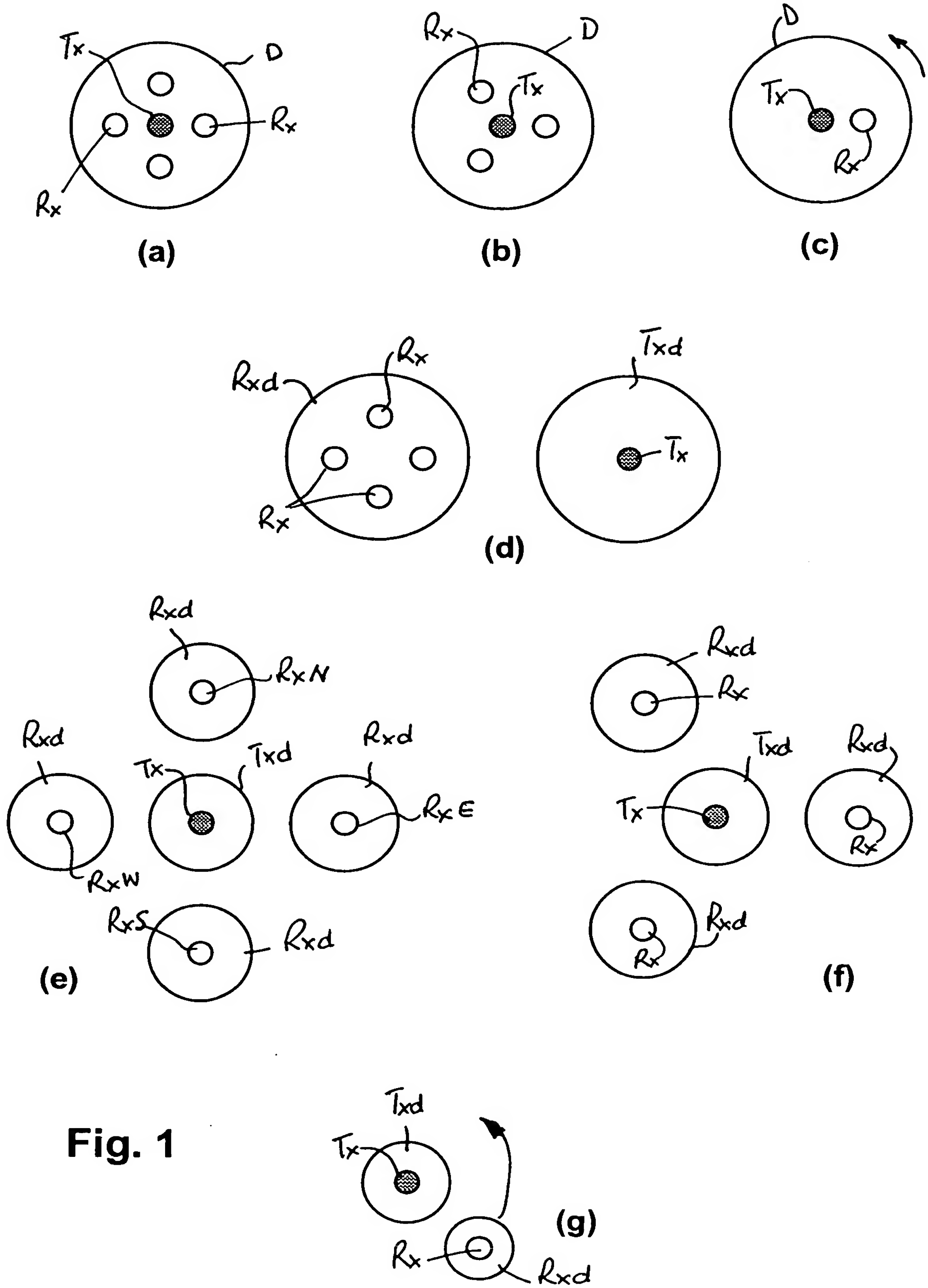
Figure 13 shows illustrates a composite chart showing wind speed and direction with altitude taken from another series of measurements using the apparatus of Figure 11.

Figure 14 shows the phase difference [arbitrary scale] between the signals obtained from the East and West receivers of the apparatus of Figure 11 during another series of experiments. In this case, the horizontal axis indicates the digital sample number of the received signals. Since the digital sampling took place at about 96.6 kHz, this axis is indicative of altitude.

While some examples of the application of the invention have been described, it will be appreciated that the methods of the present invention can be applied widely to acoustic sounding and that many alterations and additions can be made without departing from the scope of the invention as outlined above.

****

Tele-IP Limited
By its Attorney
Paul A Grant


Tx
D
Rx
Rx
(a)
Rx
D
Tx
(b)
D
Tx
Rx
(c)
Rxd
Rx
Txd
Tx
Rx
(d)
Rxd
RxN
Rxd
Tx
Txd
Rxd
RxE
RxW
RxS
Rxd
(e)
Rxd
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Rxd
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Rx
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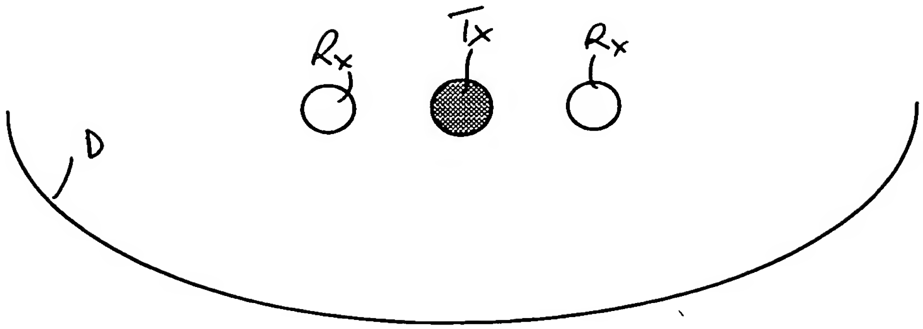
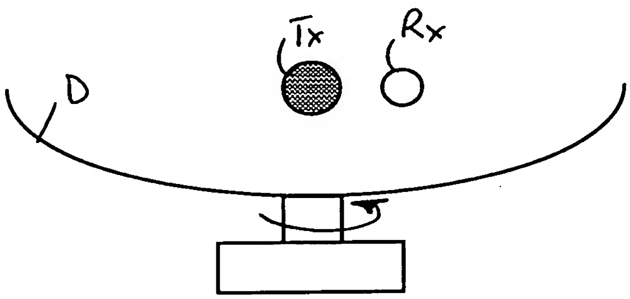
Rxd
(f)
Txd
Tx
(g)
Rx
Rxd

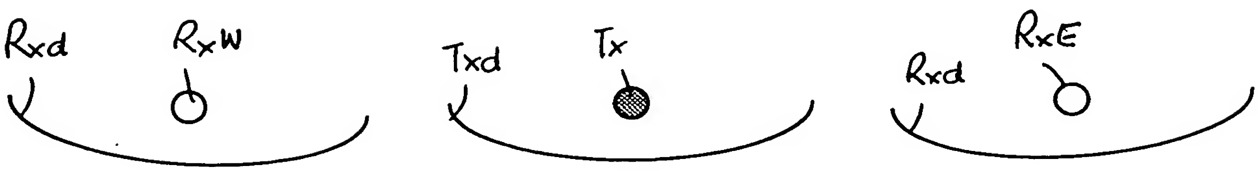
Fig. 1



(A)



(C)



(E)

Fig. 2

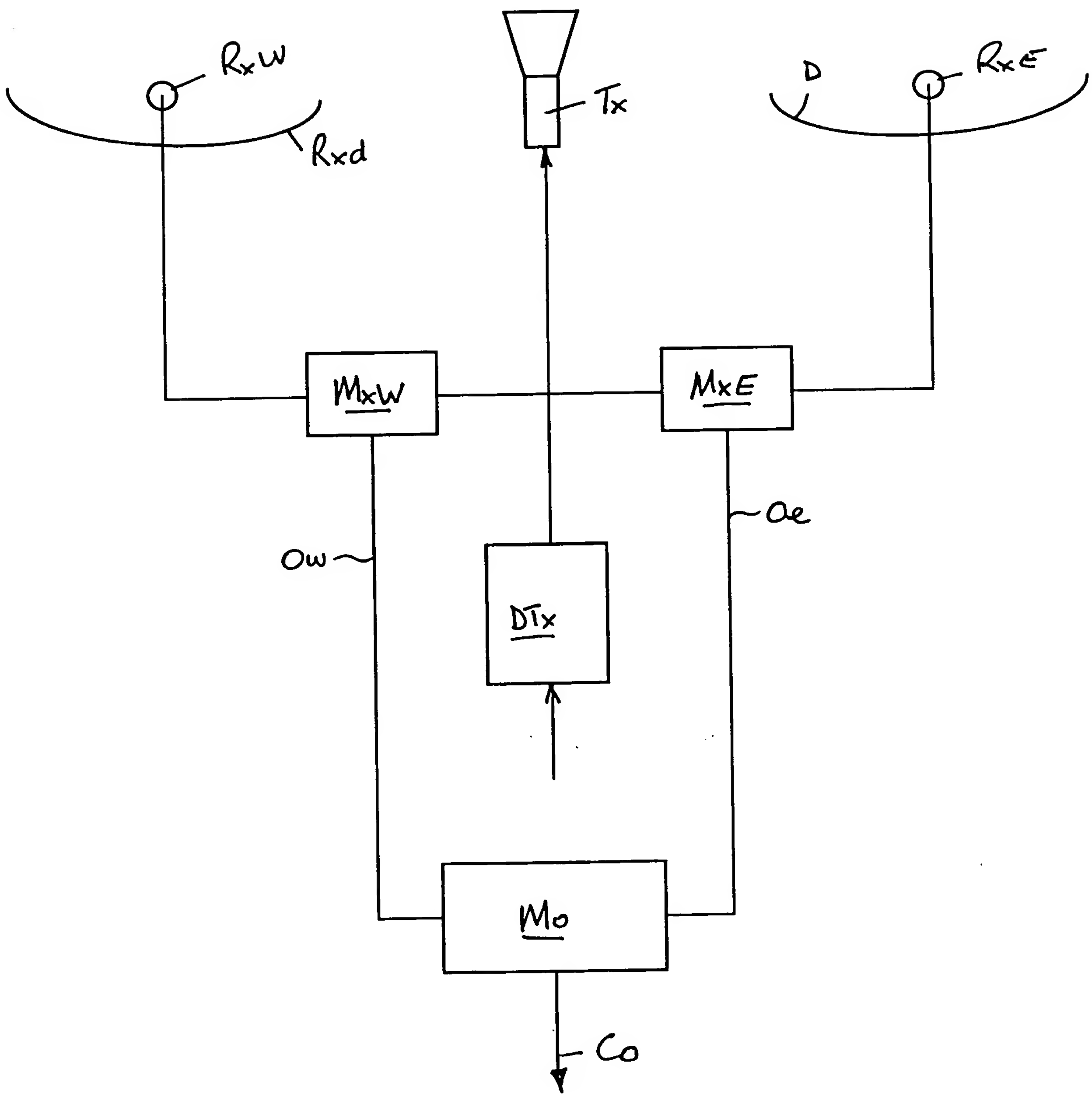


Fig. 3

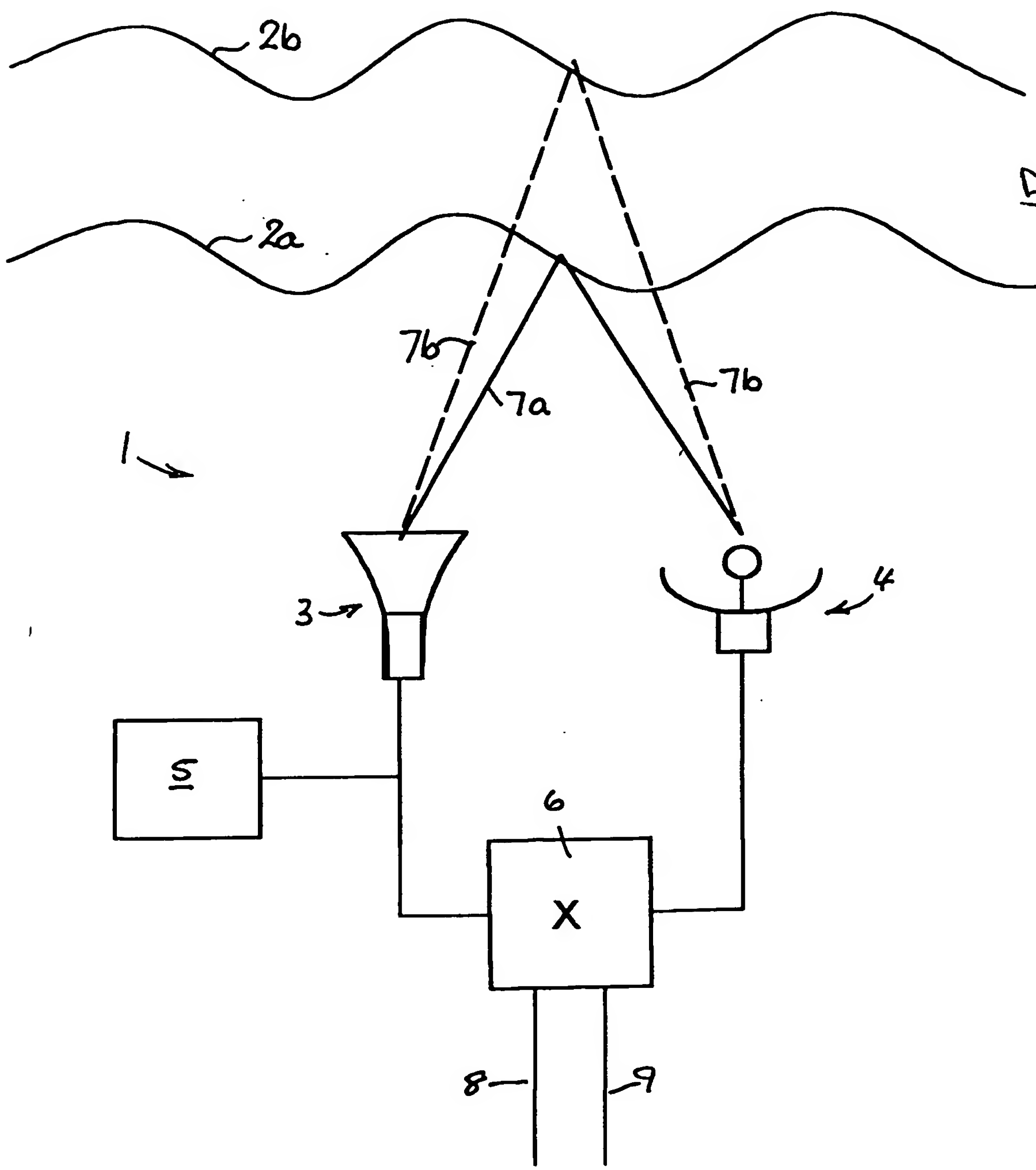


Fig. 4

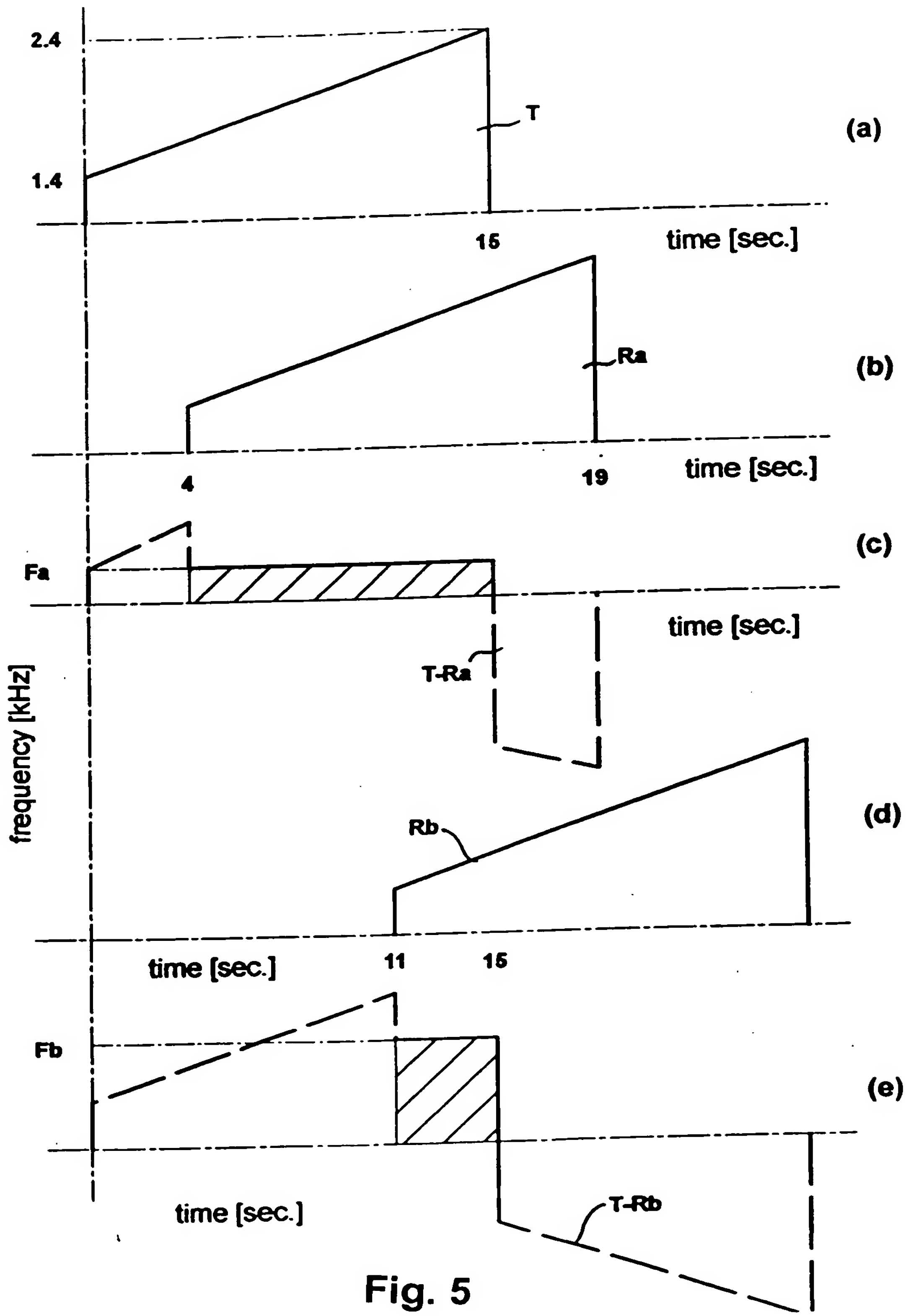

2.4
1.4
T
(a)
15
time [sec.]
Ra
(b)
4
19
time [sec.]
Fa
(c)
time [sec.]
T-Ra
frequency [kHz]
Rb
(d)
time [sec.]
11
15
Fb
(e)
time [sec.]
T-Rb

Fig. 5

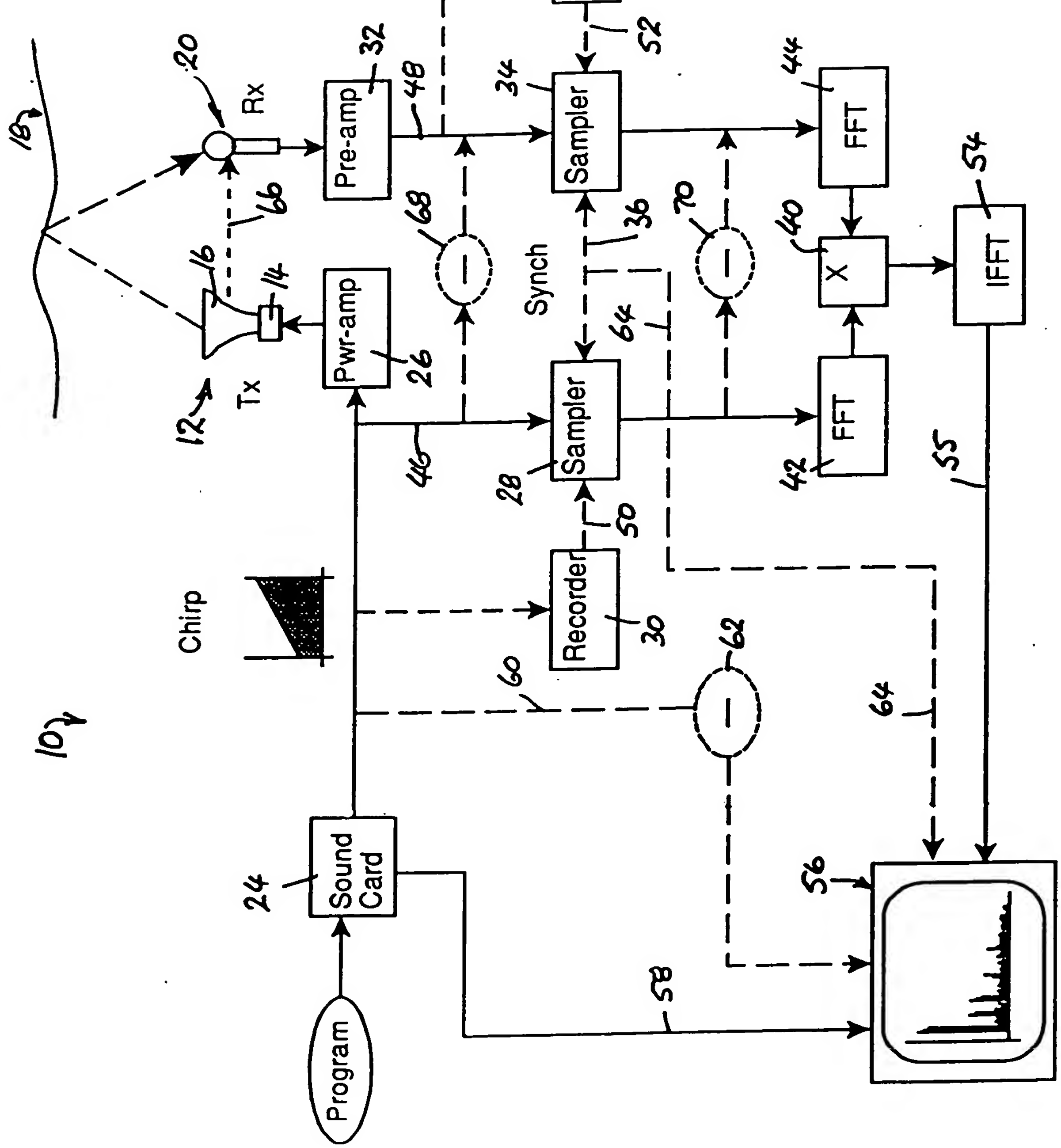
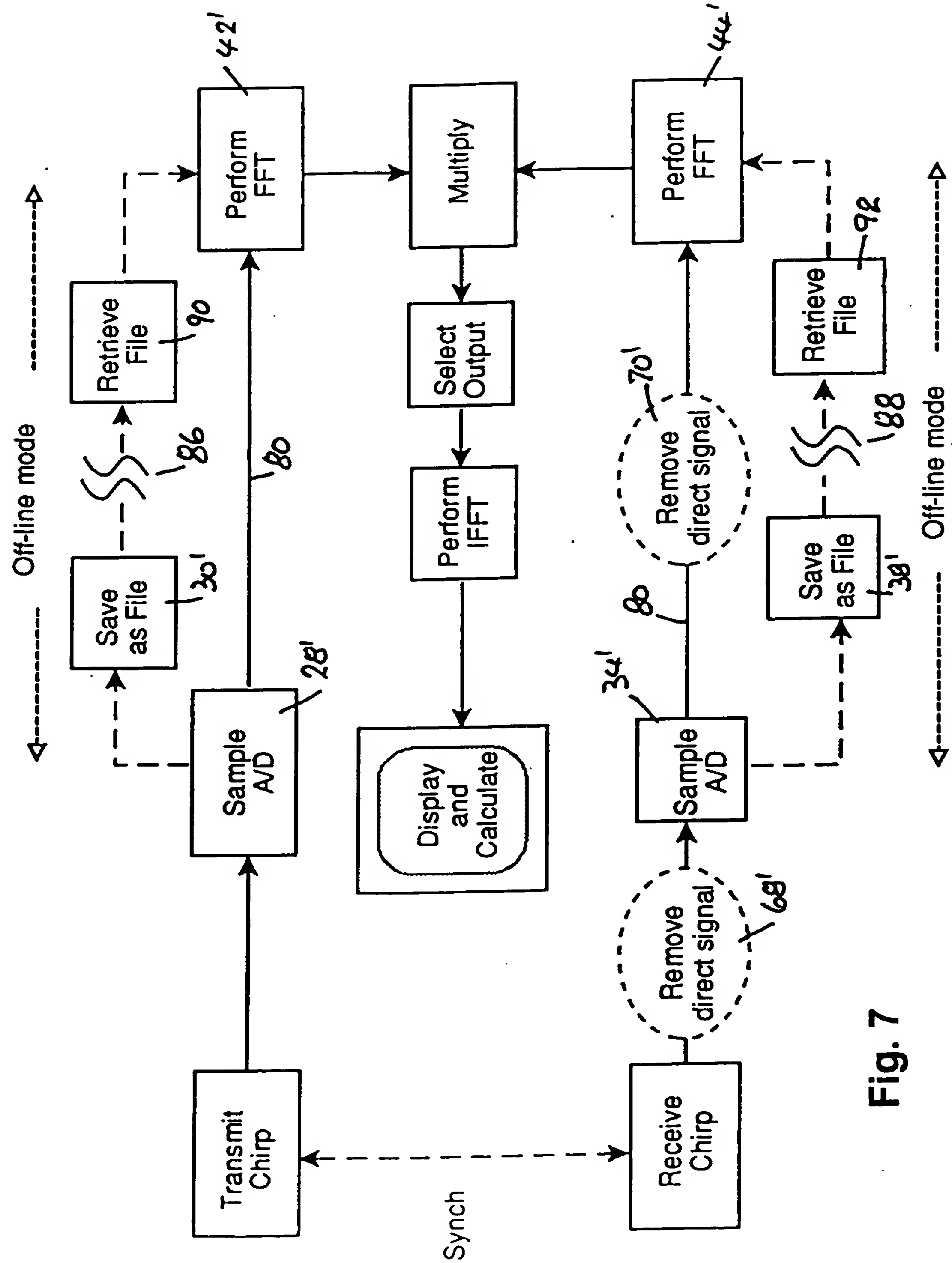
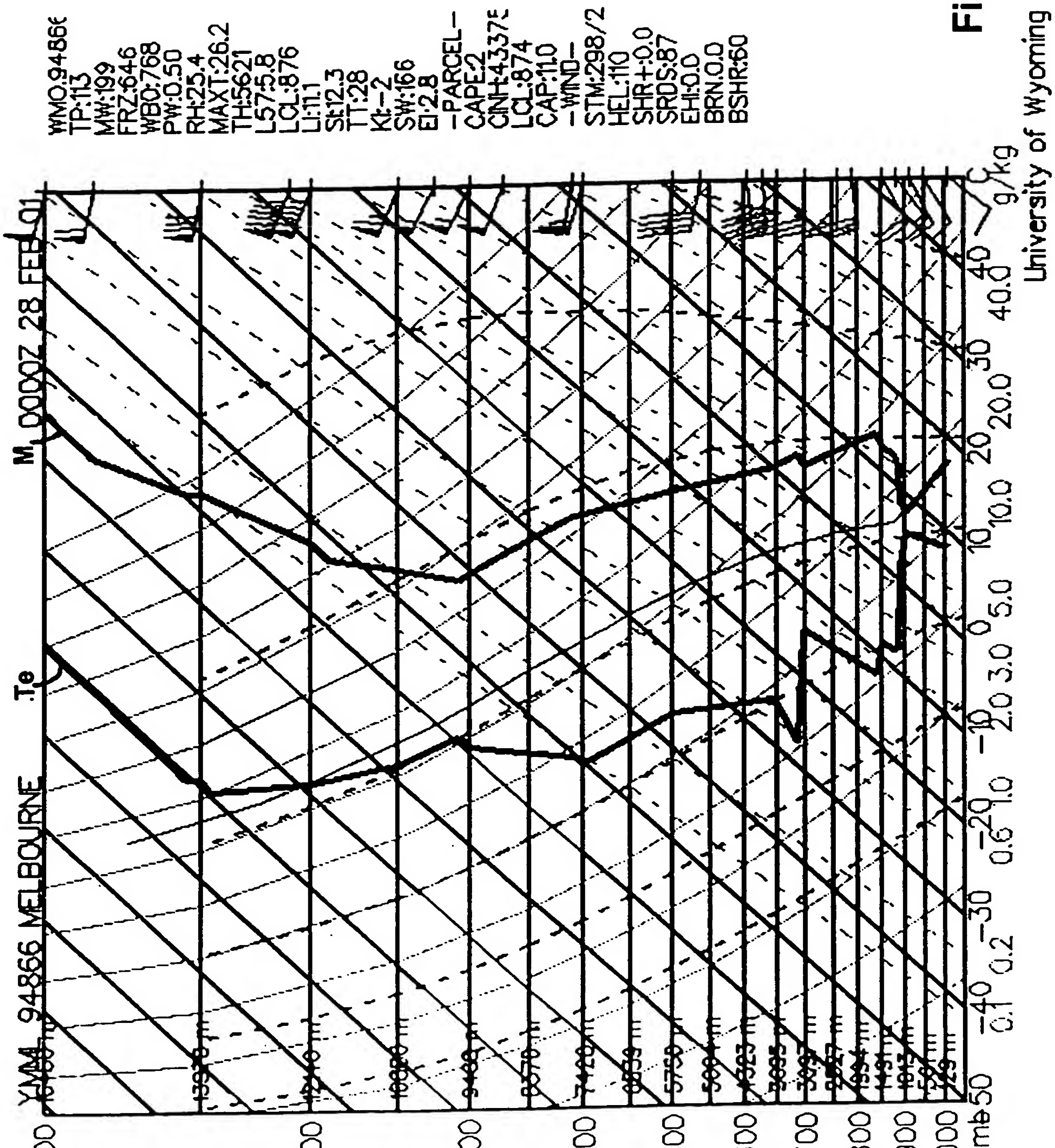

10
12
14
16
18
20
Rx
Tx
Chirp
Program
Sound Card
24
Pwr-amp
26
Pre-amp
32
Recorder
30
Recorder
38
Sampler
28
Sampler
34
Synch
36
FFT
42
FFT
44
X
40
IFFT
54
46
48
50
52
55
56
58
60
62
64
66
68
70

Fig. 6



Off-line mode
Save as File
30'
86
Retrieve File
90
Perform FFT
42'
Transmit Chirp
Sample A/D
28'
80
Multiply
Select Output
Perform IFFT
Display and Calculate
Synch
Receive Chirp
Remove direct signal
68'
Sample A/D
34'
80
Remove direct signal
70'
Perform FFT
44'
Save as File
38'
88
Retrieve File
92
Off-line mode

Fig. 7



YMML 94866 MELBOURNE
00007 28 FEB 01
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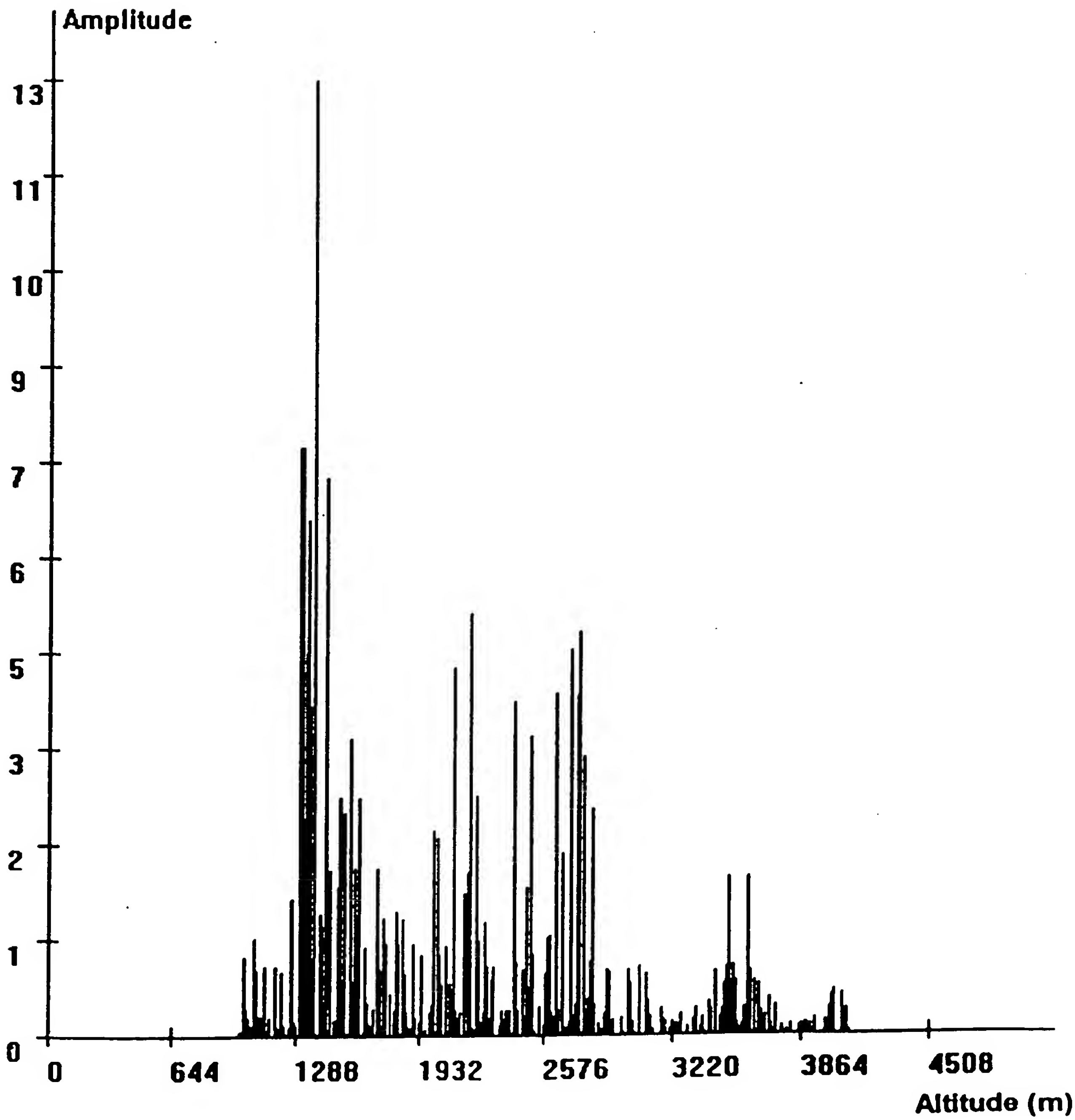
TP:113
MW:199
FRZ:646
WBO:768
PW:0.50
RH:25.4
MAXT:26.2
TH:5621
L57:5.8
LCL:876
LI:11.1
SI:12.3
TT:28
KI:-2
SW:166
EI:2.8
-PARCEL-
CAPE:2
CINH:4337
LCL:874
CAP:11.0
-WIND-
STM:298/2
HEL:110
SHR:+0.0
SRDS:87
EHI:0.0
BRN:0.0
BSHR:60
mb
100
200
300
400
500
600
700
800
900
1000
-50
-40
-30
-20
-10
0
10
20
30
40
C
0.1
0.2
0.6
1.0
2.0
3.0
5.0
10.0
20.0
40.0
g/kg
University of Wyoming

Fig. 8



Amplitude
13
11
10
9
7
6
5
3
2
1
0
0
644
1288
1932
2576
3220
3864
4508
Altitude (m)

Fig. 9

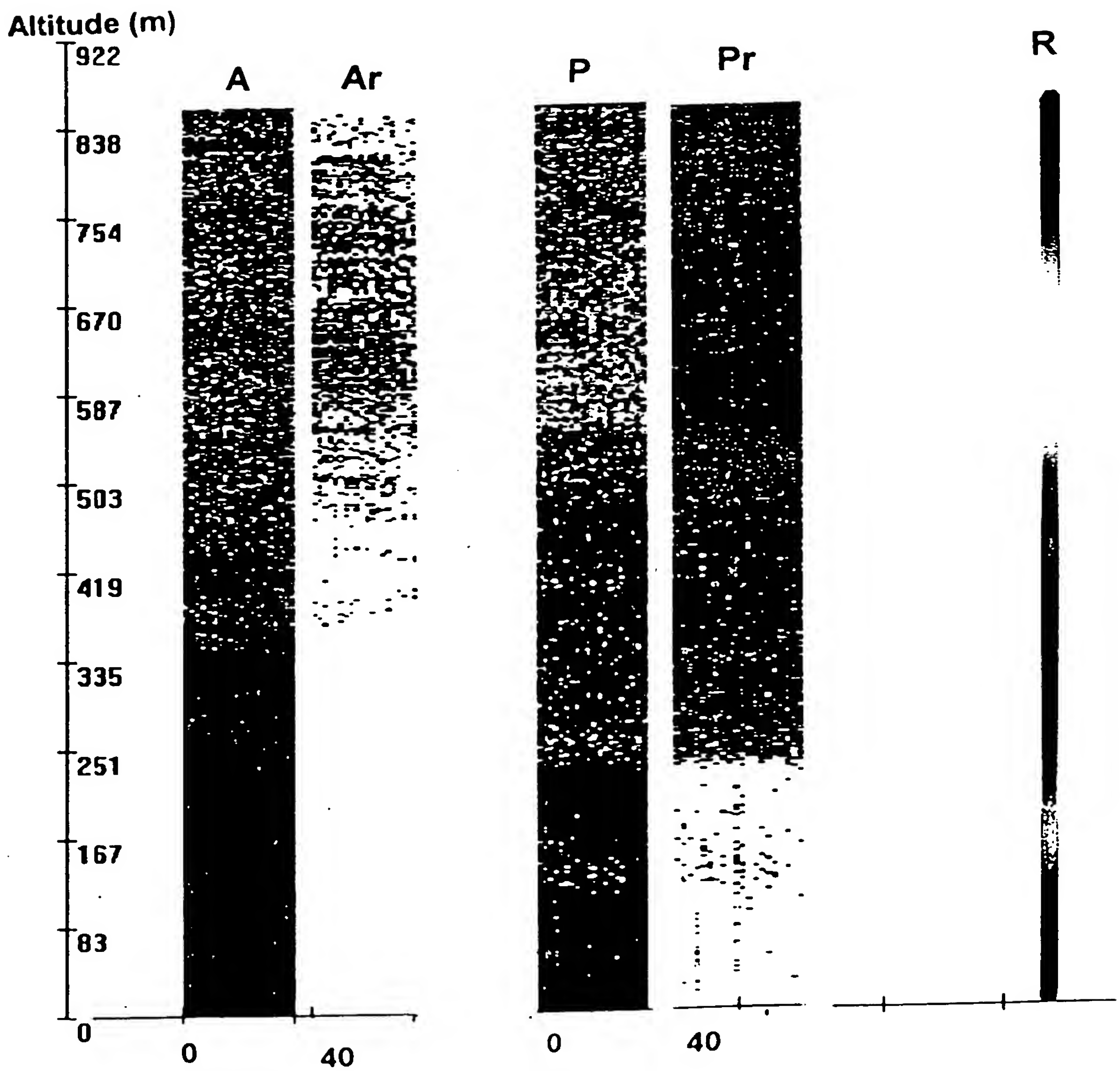

Altitude (m)
922
838
754
670
587
503
419
335
251
167
83
0
A
Ar
P
Pr
R
0
40
0
40

Fig. 10

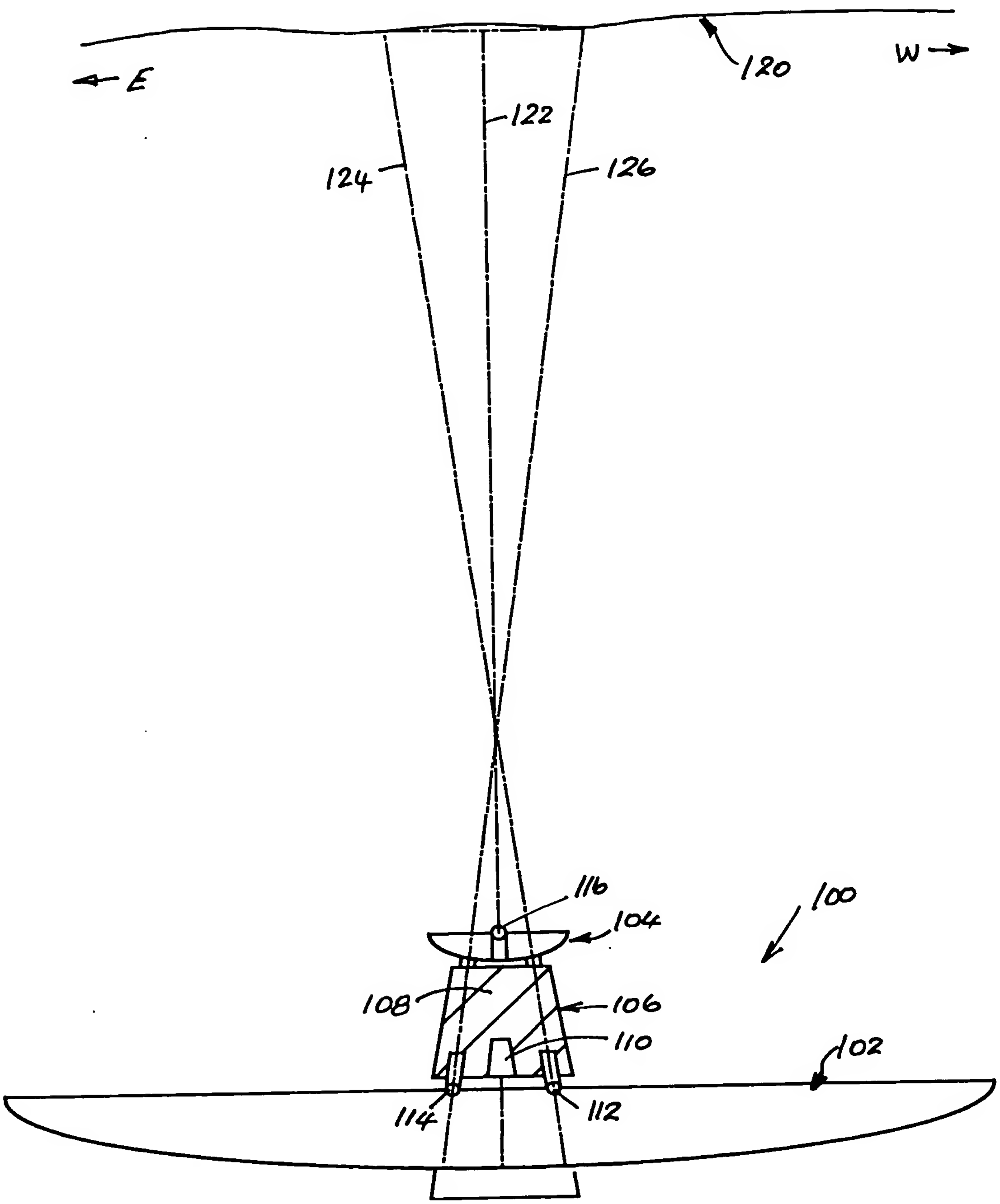


Fig. 11

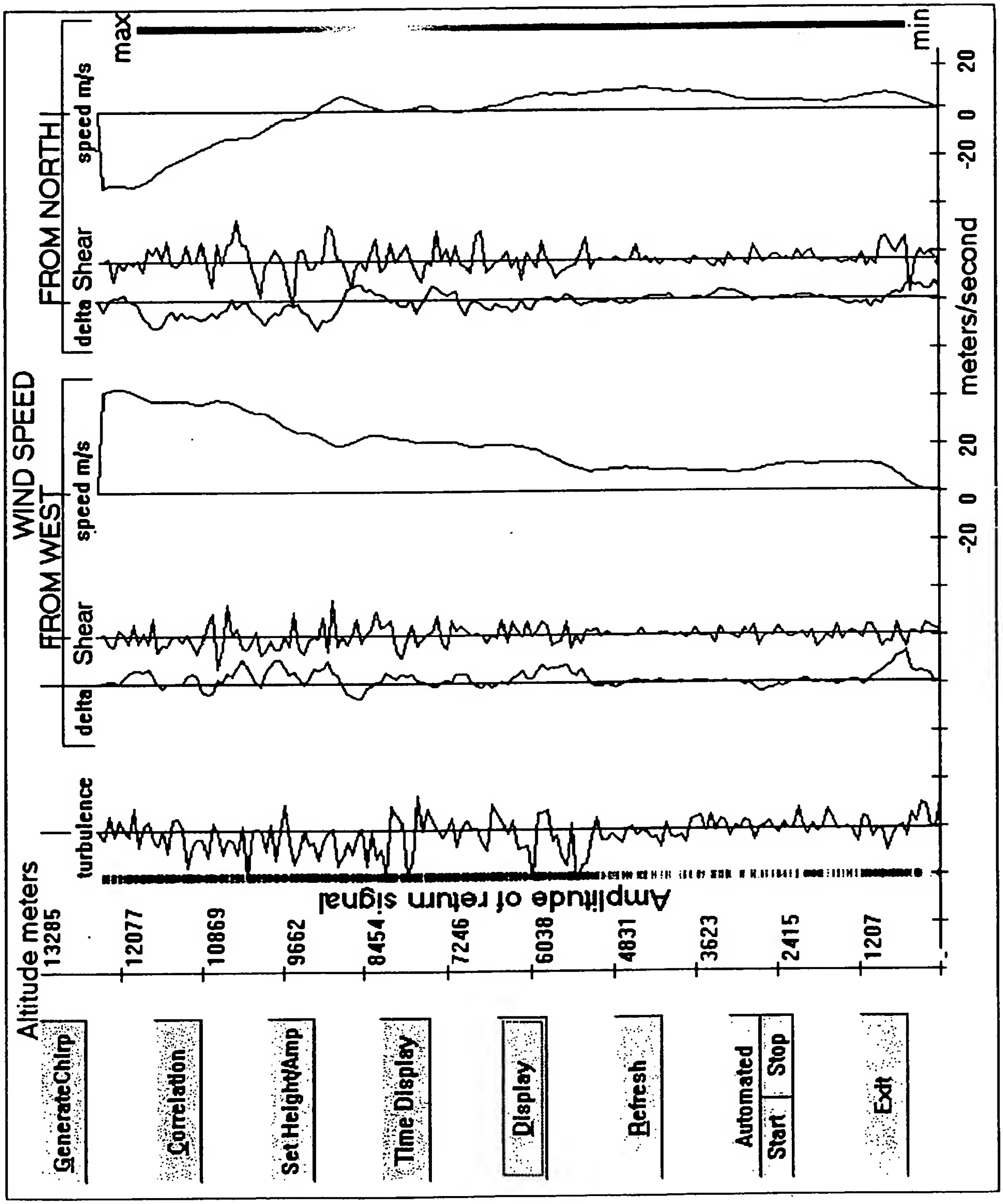

WIND SPEED
FROM WEST
FROM NORTH
delta
Shear
speed m/s
turbulence
max
min
-20
0
20
meters/second
Altitude meters
13285
12077
10869
9662
8454
7246
6038
4831
3623
2415
1207
Amplitude of return signal
GenerateChirp
Correlation
Set Height/Amp
Time Display
Display
Refresh
Automated
Start
Stop
Exit

Fig. 12

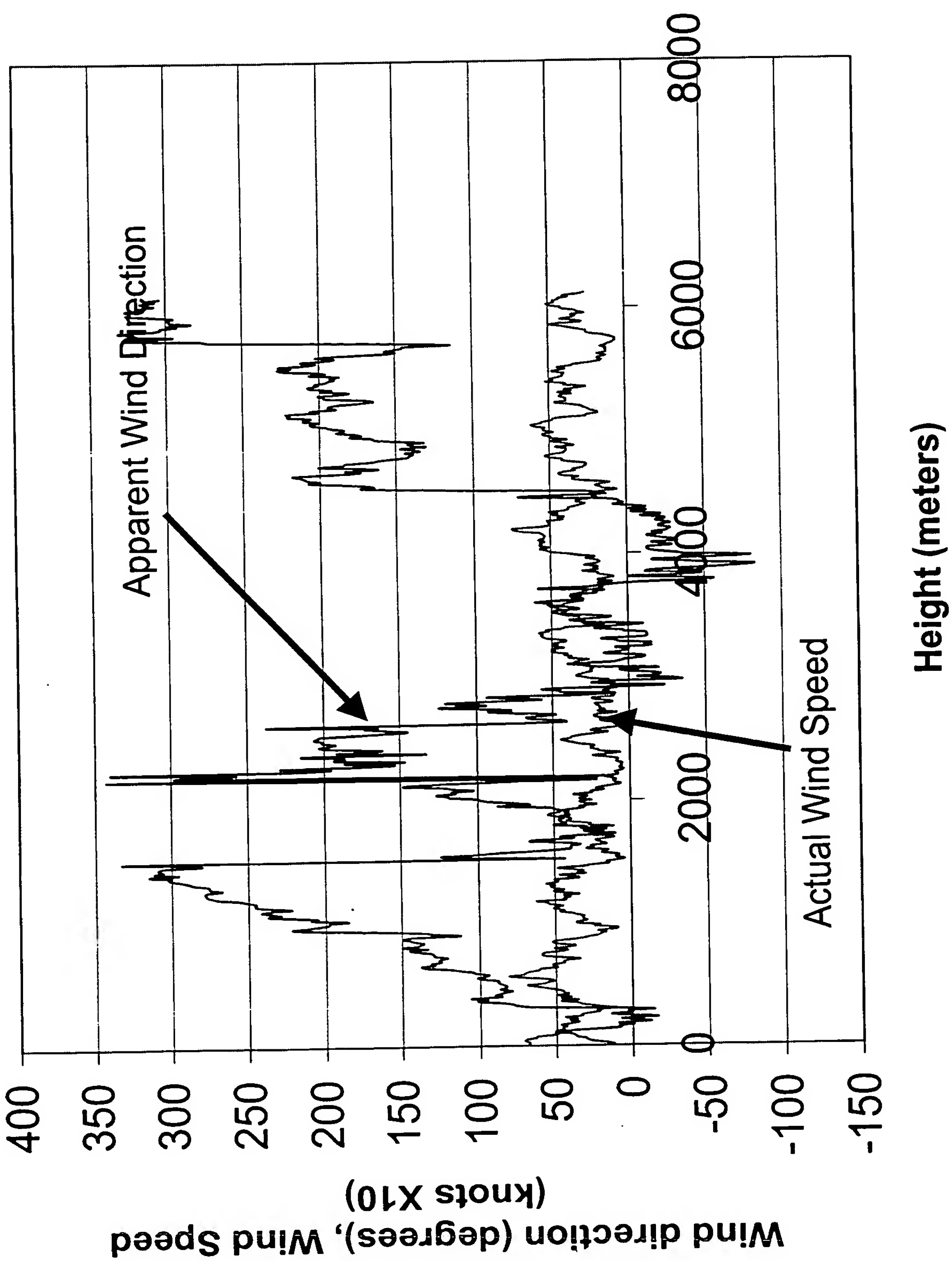
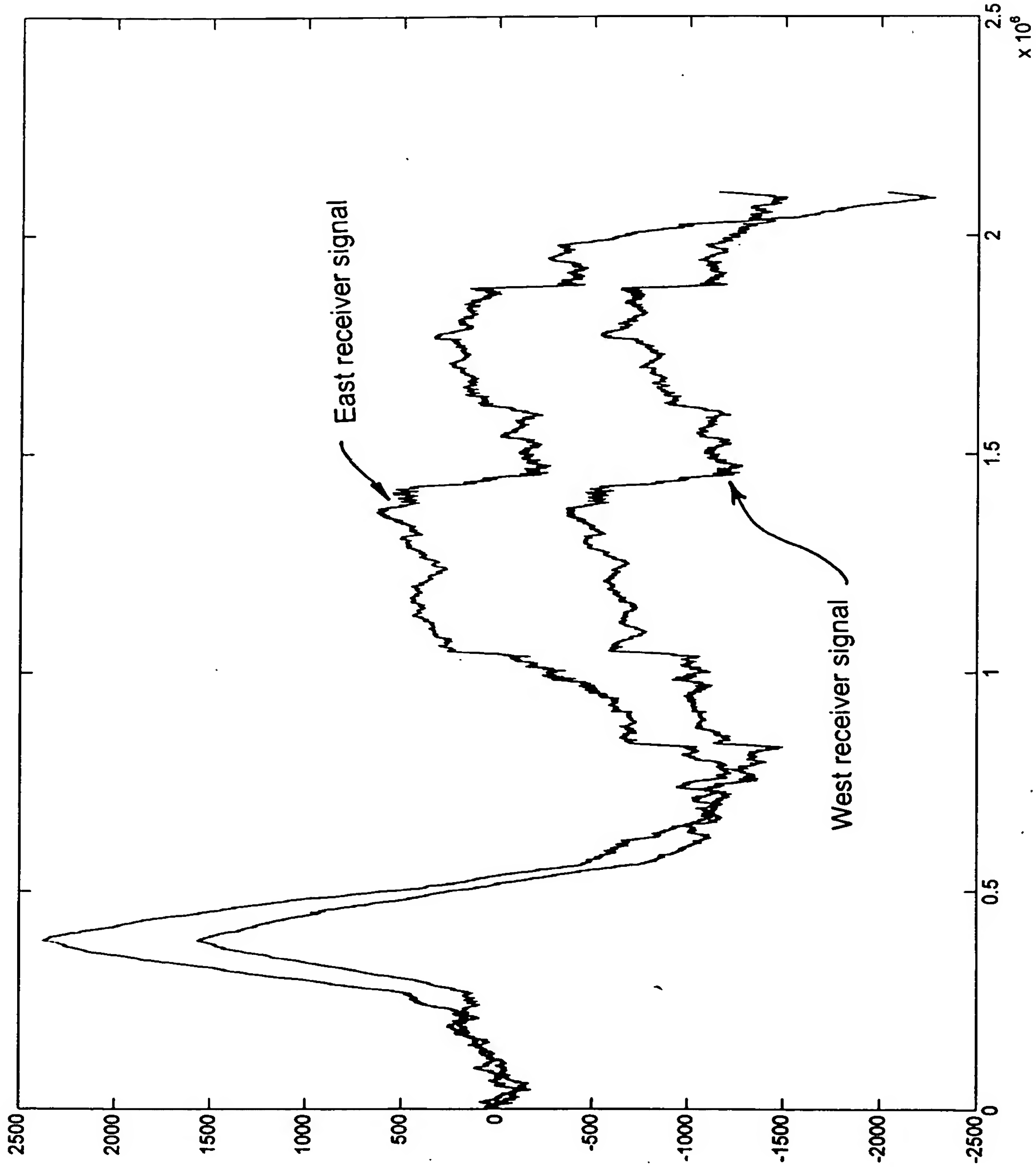

Apparent Wind Direction
Actual Wind Speed
Height (meters)
Wind direction (degrees), Wind Speed (knots X10)
400
350
300
250
200
150
100
50
0
-50
-100
-150
0
2000
4000
6000
8000

Fig 13

Fig. 14



East receiver signal
West receiver signal
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
0
0.5
1
1.5
2
2.5
x 10^6